Wellhead Fire Suppression with Water Sprays

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Objective: To develop blowout fire suppression technology for offshore oil and gas operations.

The Center for Fire Research (CFR) of the National Bureau of Standards (NBS) is investigating the feasibility of controlling the radiation from, and the extinguishment of, blowout fires by use of a water spray fire suppression system. When water is added to any hydrocarbon fuel fire, even in small amounts, radiation from the flames is reduced. It has been found in this research that when sufficiently large amounts of water are added, simulated gas wellhead fires can be extinguished. Research has focused on analysis of radiation from simulated gas well blowout fires, testing of a prototype water spray fire suppression system with obstructed gas jet fires, and measurement of radiation from combined liquid and gas hydrocarbon jet flames.

A series of large scale simulated gas wellhead fire suppression tests were conducted in Norman, Oklahoma in 1984 to evaluate the performance of a four nozzle water spray system to extinguish or limit radiation from the fire (Evans and Phenning, 1985). An arrangement of four water spray nozzles placed symmetrically about a 0.1 m (4 in) diameter gas outlet to spray water vertically into and around a methane gas jet flame was tested. It was found that an unobstructed nominally 200 MW [5.6 m^3/s (17 MMSCF/D[1]) methane] jet-flame could be extinguished under no wind conditions with a water flow rate of 8.1 liters/s (129 GPM), but would continue to burn with a lower water injection rate of 5.4 liters/s (86 GPM). For scaling purposes and application of the results to other fires, these results can be recast in terms of the water spray to methane mass flow rate ratio. In these terms the fire was extinguished at a mass flow rate ratio of 2.2 and continued to burn at a ratio of 1.6. In the case of the fires not extinguished by the water spray, the radiation from the flame was reduced.

The flame structure and radiation properties of these large methane jet-flames were predicted using a laminar flamelet concept for turbulent flames and a narrow band radiation model developed by Faeth at the University of Michigan (Gore, et al., 1986). In this analysis, only data prior to water spray injection was used. The laminar flamelet analysis permits prediction of turbulent flame temperature by analyzing the turbulent flame as if it were equivalent to wrinkled laminar flames. Predicted and measured flame temperatures as a function of distance from the gas outlet are shown in Figure 1. Separate predictions are shown for the two representations of the initial flow conditions of the escaping gas -- divergent nozzle and momentum velocity methods. In each case, both time- [$\bar{T}$] and density weighted (Favre)- [$\tilde{T}$] (Bilger, 1976) averaged predicted mean temperatures are shown. Three experimental results all of approximately the same nominal 200 MW energy

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[1] Million standard cubic feet per day at 1 atm. and 15.5 °C.

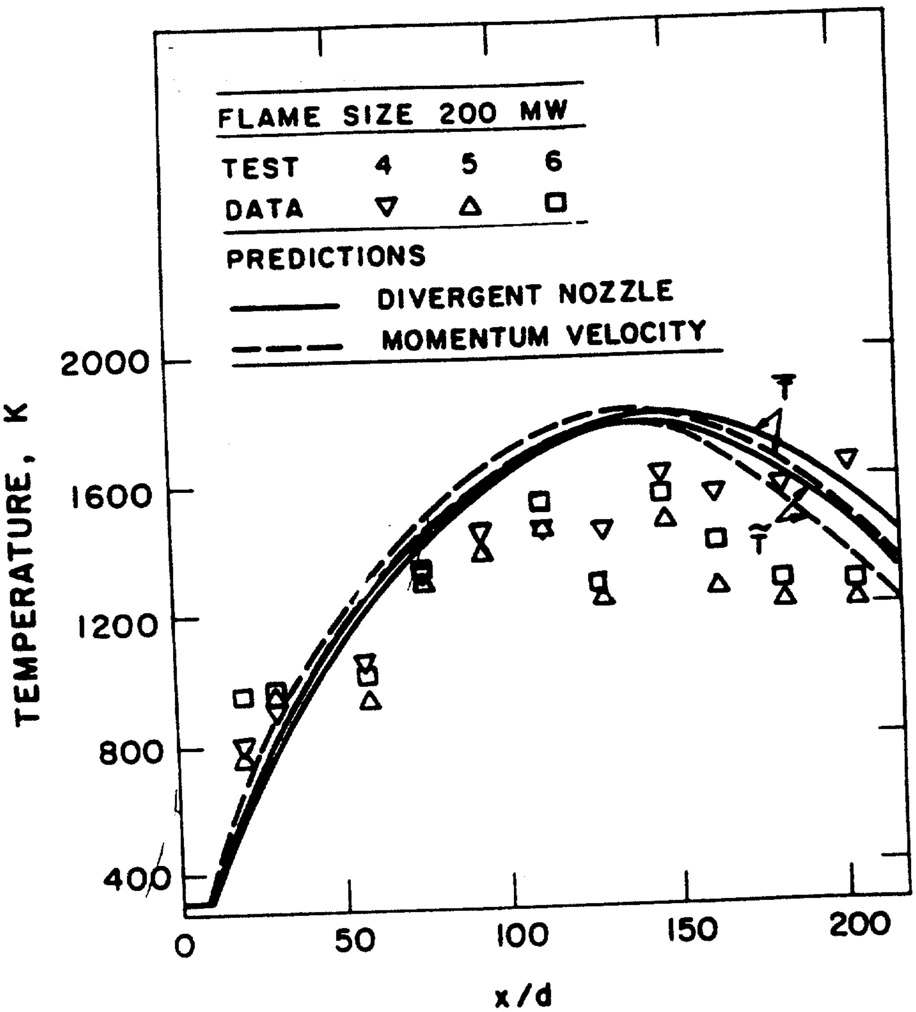

Figure 1. Measured and predicted mean temperatures along the axis of 200 MW jet-flame

release rate test conditions except for minor wind variations are shown to compare to the calculated result for 200 MW and no wind. Wind disturbances during the tests deflect the flame off axis, causing measured temperatures to be too low, particularly at locations far from the gas outlet. The comparison between predictions and measurements is encouraging. Measured maximum temperatures are roughly 200 K below the predictions, which is reasonable in view of probable thermocouple error from radiation heat losses and the effects of wind disturbances.

Predicted and measured flame radiation heat fluxes at five positions around the flame are contained in Table 1. Only one prediction is given for the nominal condition of 200 MW energy release rate. For comparison purposes the data from the three tests are averaged.

	DETECTOR				
	1	2	3	4	5
TEST #					
4	6.1	10.4	5.7	5.7	7.0
5	5.1	8.3	5.0	5.8	7.1
6	5.6	7.2	4.3	5.2	6.6
MEAN	5.6	8.6	5.0	5.6	6.9
STD DEV.	0.5	1.6	0.7	0.3	0.3
PREDICTIONS	5.17	6.82	4.49	6.68	5.24

TABLE 1. Measured and predicted radiation heat fluxes (kW/m^2) from 200 MW Commercial Grade Methane Jet-flames

Predictions in Table 1 generally underestimate the experimental results. The average discrepancy between predictions and measurements in Table 1 is 20%, which is quite good in view of the fact that ambient wind disturbances are not accounted for in the predictions. Also turbulent radiation interactions, that were ignored in the calculation tend to increase calculated radiation levels from the mean property predictions shown here by roughly 10% for a methane/air flame.

This work is being expanded to predict the more intense radiation emitted from combined methane gas and crude oil flames. If these calculations are also successful, the radiation mitigating effects of water spray on flame radiation may also be calculated using the same analysis techniques.

Through a research grant to Professor Bourgoyne at Louisiana State University, additional testing of the water spray blowout suppression concept was completed (Chauvin and Bourgoyne, 1988). The facilities at the Blowout Prevention school in the Department of Petroleum Engineering permitted both fire tests of greater energy release rates, up to 410 MW (35 MMSCF/D) (McCaffrey and Evans, 1986), and evaluation of the effects of obstructions that stabilize the flame. The same gas flow outlet and spray system used in previous tests in Norman, Oklahoma was used in these tests. Figure 2 shows a compilation of the test results in terms of water spray to gas mass flow rate ratio vs. gas flow rate. At relatively large gas flow rates, unobstructed

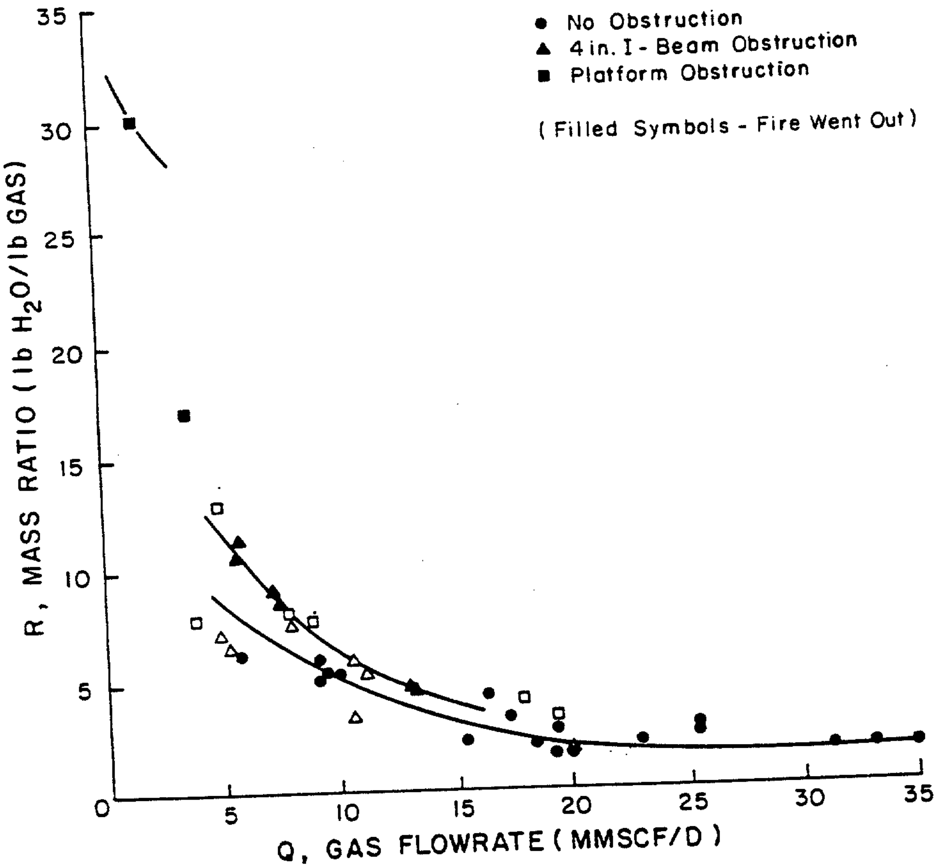

Figure 2. Water spray extinction of obstructed and unobstructed large-scale simulated gas-well blowout fires

fires were extinguished at a mass flow rate ratio of 2 over the range of fires (20 to 35 MMSCF/D) representing relatively high gas outlet velocities. This supports earlier measurements made at Norman, Oklahoma and provides some support to extension of results to even larger fires representing actual gas-well blowouts. At lower gas flow rates increasing ratios of water to gas were need to extinguish the fire. This reflects the poor mixing and spray break-up in the relatively lower velocity gas jet.

The effect of any obstruction in the gas flow is to increase the ratio of water to gas needed to extinguish the fire. The process of extinction also becomes more erratic as seen by the filled symbols (representing fire extinction) immediately adjacent to open symbols (representing sustained burning). In the case of the broad platform obstruction, fire extinction required mass flow rate ratios greater than fifteen.

It has been seen in smaller scale testing at NBS that even though extinction is more difficult with obstructions in the flame, the increased stability of the obstructed flame allowed greater reduction in the flame radiation through reduced emissions and water spray shielding.

Data have been collected at NBS on the effects of water spray on combined gas and liquid hydrocarbon flames. Tests with total energy release rates of 20 MW, half from methane and half from heptane have shown that the these fires containing liquid fuel are more difficult to extinguish with water spray than pure gas fires having the same total energy release rate. The combustion of the liquid fuel produces a highly radiative flame. Water sprayed into the heptane-methane jet flame can reduce radiation from the flame to one-quarter of its initial intensity. Experiments are being continued to assess the effects of water spray on combined crude oil and methane simulated well blowout fires.

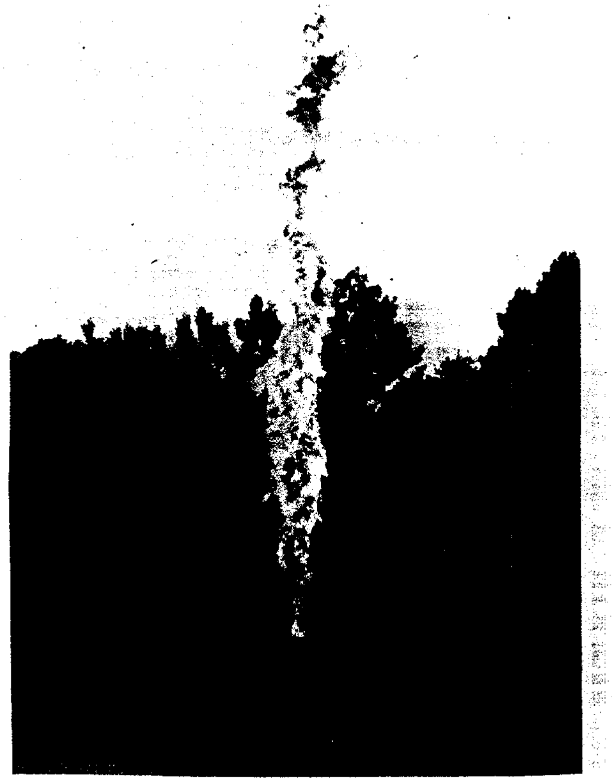

Figure 3. Twenty Megawatt combined heptane-methane simulated blowout fire at NBS test facility

References

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